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REVIEW ARTICLE

Special Issue - Potential of Food By-Products

Potential of Food By-Products

Natural Pectin Sources, Extraction Methods, Chemical Composition, and Emerging Applications in Food Systems: A Systematic Review

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ABSTRACT

Background: Pectin is a naturally occurring polysaccharide widely used in the food industry for its rheological and textural properties. Despite its significance, there is a need to explore diverse sources and extraction methods to meet the growing demand for pectin in food systems worldwide.

Aims: This study aimed to review sources, extraction methods, chemical compositions, and applications of natural pectin globally, emphasizing advancements and trends from 1980 to 2024.

Materials and Methods: Peer-reviewed literature on natural pectin was systematically retrieved from online databases, including Google Scholar, Google, Web of Science, Scopus, and PubMed. The review adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines. A total of 48 scientific articles were selected based on relevance.

Results: The majority of articles (28) were published between 2020 and 2024, reflecting increased research interest due to rising demand for pectin. Geographically, most studies originated from Asia (31), followed by Africa (6), South America (4), North America (3), Europe (3), and Oceania (1). Conventional extraction methods (28 articles), such as acid extraction and hot water extraction, were more prevalent compared to green technologies (20 articles) like microwave and ultrasound-assisted extraction. Citrus fruits were the predominant source of pectin, with acid extraction being the most common method.

Conclusion: It has been depicted that there is increasing demand for natural pectin, yet only citrus fruits are mostly utilized using conventional methods. Thus, there is a need to diversify pectin sources beyond citrus fruits and to adopt green technology extraction methods to enhance sustainability as well as exploring regions like Africa, where demand for pectin is increasing.

Keywords: Natural Pectin; Underutilized Sources; Extraction Method; Food Industry Application; Green Technology; Systematic Literature Review.

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1 INTRODUCTION

Pectin constitutes a structurally heteropolysaccharide primarily composed of covalently α-1,4-linked D-galacturonic acid (GalA) units, localized in the primary cell walls and middle lamella of higher plants (Chan *et al.,* 2017; Mohnen, 2008). This molecule consists of long-chain galacturonan segments interspersed with fneutral sugars such as rhamnose, arabinose, galactose, and xylose. These structural features enable pectin to form a matrix with celluloses and hemicelluloses, contributing to plant cell structure (Khan *et al.,* 2013). Unlike other polysaccharides, pectin lacks a defined molecular weight due to variations in sugar moieties and degrees of methyl esterification (Geerkens *et al.,* 2015). The degree of esterification (DE) significantly influences pectin's functional properties. Pectin is categorized into low methoxyl pectin (DE < 50%) and high methoxyl pectin (DE > 50%), each with distinct physicochemical properties and applications (Liu *et al.,* 2010; Yapo *et al.,* 2009). For instance, low methoxyl pectin is commonly utilized in low-calorie products including dietetic jams and jellies (Wai *et al.,* 2010).

1.1 Functional Properties and Applications

Pectin serves as a thickening, stabilizing, emulsifying, and gelling agent in various food products. Pectin also functions as a fat substitute and health-promoting ingredient (Babbar *et* al., 2016; Min et al., 2010). Pectin-derived oligosaccharides, including rhamnogalacturonan, homogalacturonan, and arabino oligosaccharides, act as dietary fibers, prebiotics, and texturizers, making them valuable in functional foods (de Oliveira et al., 2024; Yüksel et al., 2025). Emerging applications include the utilization of pectin polymers in edible films and coatings, improving texture and shelf life in products such as yogurts and dairy desserts (Valdés et al., 2015; Ralet et al., 2001). Beyond food, pectin exhibits antioxidant, anti-inflammatory, antibacterial, and wound-healing properties, making it highly valuable for pharmaceutical applications. Its capacity for fat absorption, ion binding, and antiglycation, as well as potential roles in cancer treatment, further underscore its therapeutic versatility (Bartolazzi, 2018; Giusto et al., 2017; Koriem et al., 2014).

1.2 Natural and Synthetic Pectin

Natural pectin is primarily extracted from plant materials rich in galacturonic acid residues such as citrus fruits and apple pomace, (Roman-Benn et al., 2023). Variations in plant sources and extraction methods, including acidic and enzymatic approaches, significantly influence the quality and functionality of the extracted pectin (Thakur et al., 1997). For instance, citrus fruits are recognized to produce high-quality pectin with strong gelling properties due to their high methoxyl content (Guo et al., 2012). Factors such as fruit ripeness and extraction conditions including temperature, pH and solvent type play crucial roles in determining pectin's molecular structure and functionality (Xiang et al., 2024; Haque et al., 2025). Modified pectin, a chemically modified alternative, offers tailored functional properties for specific applications in food and pharmaceuticals (Freitas et al., 2021). However, increasing consumer preference for natural ingredients and the growing clean-label movement have constrained the market acceptance of chemically modified pectins, despite their enhanced functional performance in food and pharmaceutical applications (Xiang et al., 2024).

1.3 Extraction Methods and Characterization

Microwave-assisted extraction has emerged as a promising method, significantly reducing extraction time while maintaining pectin quality (Bagherian et al., 2011). Characterization techniques such as rheology, infrared spectroscopy, and nuclear magnetic resonance spectroscopy provide valuable insights into pectin's molecular properties, optimizing its applications in food systems (Nasirinezhad et al., 2025). With rising consumer demand for natural food additives and clean-label products, natural pectin derived from fruits and vegetables is increasingly favored over synthetic alternatives (Yamada, 1996). Therefore, there is an imperative to explore more sources of natural pectin especially the underutilized as well as researching on green technology methods of extraction that are sustainable to quench the increasing demand for natural food additives. This review synthesizes current literature on natural pectin sources, extraction methodologies, applications in food systems and global research distribution. By exploring these facets, it highlights the pivotal role of pectin in modern food technology and identifies ongoing research trends and future directions.

2 Methodology

2.1 Data Retrieval and Analysis

A structured literature search was conducted to find published literature worldwide focusing on the objective of this review. The reporting of this systematic review was guided by the standards of the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) Statement (Moher et al., 2009). The systematic search was carried out using keywords: "natural pectin", "underutilized sources", "extraction", "characterization", "application", "food industry". The search was conducted considering the following databases: Web of Science, Scielo, Scopus, Google Scholar, Google, AJOL, and PubMed.

The relevant book chapters and peer-reviewed journal articles were utilized for selecting the literature. Publications from reputable academic institutions, international organizations, universities, and online libraries of conference proceedings were also analyzed. A summary of the inclusion and exclusion criteria is shown in PRISMA 2020 flowchart diagram (Figure 1) and PRISMA 2020 checklist is provided in (Supplementary Table). The reported data were extracted from figures, tables and text of the selected studies. After the selection of scientific papers, the relevant data were extracted from each included study and summarized in thematic tables and graphs.

3 Results and Discussion

A total of 48 articles met the inclusion criteria. The selected scientific papers were arranged from latest article to the oldest as summarized in Table 1. The reviewed articles display the different sources of pectin, extraction methods, and the application of pectin in the food industry. For the period under review, China (8) contributed most of the articles.

3.1 Distribution of Reviewed Articles

The results displayed in Table 1 and Figure 2 reveal that the oldest article was published in 1988, and the highest number of articles (28) were published in the period ranging from 2020 to 2024.

Table 1. Sources of Pectin, Extraction Methods and Application of the Extracted Pectin

	Author &Year	Country	Pectin source	% Yield	Degree of esterification	Extraction method	Application
1	Dambuza *et al.* (2024)	South Africa	Lemon peel	16.1%	68.4%	Acid extraction	
2	Sangta *et al.* (2024)	Thailand	Coffee pulp	13.7%	78.5%	Acid extraction	Active packaging
3	Azzouzi *et al.* (2023)	Morocco	Moroccan *Citrus clementina* Peels	21.4%	38.5%	Acid extraction	-
4	Mamiru *et al.* (2023)	Ethiopia	Watermelon rind	18.2%	57.3%	Acid extraction	-
5	Jariyapamornkoon *et al.* (2023)	Thailand	Water hyacinth	5.42%	62.3%	Acid extraction	-
6	Islam *et al.* (2023)	Bangladesh	Jackfruit (*Artocarpus heterophyllus*) by-products	25.35%	38.46%	Hot water extraction	-
7	Gurev *et al.* (2023)	Romania	Apple pomace	19.1%	68.97%	Microwave assisted	-
8	Ngo *et al.* (2023)	Vietnam	Grapefruit peels	32.12%	-	Acid extraction	-
9	Şen *et al.* (2023)	Turkey	Onion waste	24.51%	-	Ultrasound-assisted	-
10	Zhu *et al.* (2022)	China	Sea buckthorn peel	8%	57.75%	Acid extraction	-
11	Lasunon *et al.* (2022)	Thailand	Tomato waste	34.1%	52.3	Ultrasound assisted	Functional foods
12	Rasidek *et al.* (2022)	Several in Asia	Banana peels	24.51%	-	Continuous subcritical water extraction system	-
13	Chien *et al.* (2022)	Taiwan	Taiwan's Citrus *depressa H.* Peels	16.07%	62.46%	Non-Acid Ultrasonic-Assisted Extraction	-
14	Spinei & Oroian (2022)	Romania	Grape pomace	28.67%	55.4%	Ultrasound assisted	-
15	Lu *et al.* (2022)	China	*Ottelia acuminata*	8.73%	-	Acid extraction	-
16	Sigiro *et al.* (2022)	Indonesia	Banana peels	2.98%	-	Acid extraction	Edible Coating
17	Peighambardoust *et al.* (2021)		Sugar beet pulp	20.7%	42.5%	Subcritical water	-
18	Dong *et al.* (2021)	China	Dried Orange peels			Microwave assisted	-
19	Karbuz & Tuğrul (2021)	Turkey	Kiwi peel	17.97%	50.9%	Microwave extraction	Dietary fiber
20	Hennessey-Ramos (2021)	Colombia	Cocoa Pod Husks	10.2%	-	Chemical and Ultrasound-Assisted Pectin Extraction	-
21	Ahmad *et al.* (2021)	Egypt	Flaxseed Cake	11.61%	43.3%	Microwave assisted Acid extraction	Pear fruit coating
22	Riza *et al.* (2021)	Indonesia	Sentul Peel (*Sandorium Koetjape*)	5.16%	-	Microwave assisted	Edible Coating of tomato
23	Sobmor & Banjong (2020)	Thailand	Thai soybean hulls	6.42%	80.81%	Intermittent microwave-assisted	-
24	Khamsucharit *et al.* (2018)	Thailand	Kepok banana peels	22.57%	37.17%	Acid extraction	-
25	Li *et al.* (2020)	China	Pomelo peels	21.67%	-	Acid extraction	-
26	Dhushane & Mahendran (2020)	Sri Lanka	Lemon Fruit peels	20.4%	-	Acid extraction	Watermelon Jam
27	Chua *et al.* (2020)		Dragon fruit peels	23.09%	33.27%	Ultrasound-assisted	-
28	Jiang *et al.* (2020)	China	Hawthorn Wine Pomace	72.89%	-	Microwave-assisted chelating agent	-
29	Fadhilah *et al.* (2020)	Indonesia	Breadnut Fruit	6.80%	46.55%	Ultrasound-assisted	-
30	Daud *et al.* (2019)	Brunei Darussalam	*Citrus maxima*	70.2%	39.2%	Acid extraction	-
31	You *et al.* (2019)	China	Pomelo peels	38.48%	-	Intermittent microwave extraction	-

In addition, the results reveal that research on pectin extraction and its application in food industry started in North America (1988), followed by Europe (1998), then Asia in 2000. Research on pectin extraction initiated a decade later (2010 – 2019) in other continents (South America, Oceania, and Africa). The observed trend on an increase in the number of published studies on pectin extraction is attributed to the shift towards clean-label and natural food products which has led to a surge in interest in natural additives such as pectin (Azzouzi *et al.,* 2023). Consumers are increasingly seeking products that do not contain synthetic additives, which has prompted researchers and food manufacturers to explore natural alternatives (Prakash Maran *et al.,* 2013). Furthermore, recent advancements in extraction methods, including green and eco-friendly techniques, have facilitate obtaining high-quality pectin from various sources. These innovations have spurred research interest and facilitated the

Table 1. Sources of Pectin, Extraction Methods and Application of the Extracted Pectin (Continued)

	Author and Year	Country	Pectin source	% Yield	Degree of esterification	Extraction method	Application
32	Sayah *et al.* (2016)	Morocco	Orange and grapefruit peels	**17.1–24.3%**	**58–72%**	Citric acid and sulphuric acid extraction	-
33	Su *et al.* (2019)	China	Orange peels	32.8%	69.8%	Surfactant and microwave assisted extraction	-
34	Wandee *et al.* (2019)	Thailand	Pomelo peel (*Citrus grandis*)	12.1–20.5%	53.9–82.5%	Acid extraction	Food hydrocolloid; potential gelling/texturizing pectin
35	Ramachandran *et al.* (2017)	India	Ripe pumpkin (Cucurbita moschata	5.33%	73.79%	Acid extraction	-
36	Fakayode & Abobi (2018)	Nigeria	Orange Peels	9.73%	-	Acid extraction	-
37	Rivadeneira *et al.* (2020)	United states	Banana peels	2.58%	-	Intermittent microwave-assisted extraction	-
38	Swamy & Muthukumarappan (2017)	Myanmar	Pomelo	3.9%	-	Base acid extraction	Jelly and milk fruit drinks
39	Kang *et al.* (2015)	China	Sunflower head	11.34%	-	Sodium citrate extraction and purified by ultrafiltration	-
40	Yuliarti *et al.* (2015)	New Zealand	Gold kiwifruit	4.48%	-	Enzyme extraction	-
41	Prakash Maran *et al.* (2014)	India	Zucchini peel	25.8%	61.2%	Microwave assisted	Edible food films
42	Prakash Maran *et al.* (2013)	India	Orange Peel	19.2%	69.3%	Microwave-assisted acid extraction	Gelling and thickening agent for food applications
43	Kumar *et al.* (2013)	Malaysia	Dried Kaffir Lime peels	61.8%	11.68%	Acid extraction	-
44	Kaya et *al.* (2014)	France/Den-mark	Dried citrus peels	16.7–33.6%	-	Acid extraction	Gelling, thickening and emulsifying agents
45	Canteri *et al.* (2010)	Brazil	Passion Fruit Rind Flours	20.34%	80%	Acid extraction	-
46	Norziah *et al.* (2000)	Malaysia	Pomelo fruit peels	20.8%	40.5%	Acetone extraction	-
47	Sun & Hughes (1998)	United Kingdom	Sugar beet pulp	9.34%	50.25%	Acid extraction	-
48	Phatak *et al.* (1988)	United States	Sugar beet pulp	7.34%	45.66%	Acid extraction	-

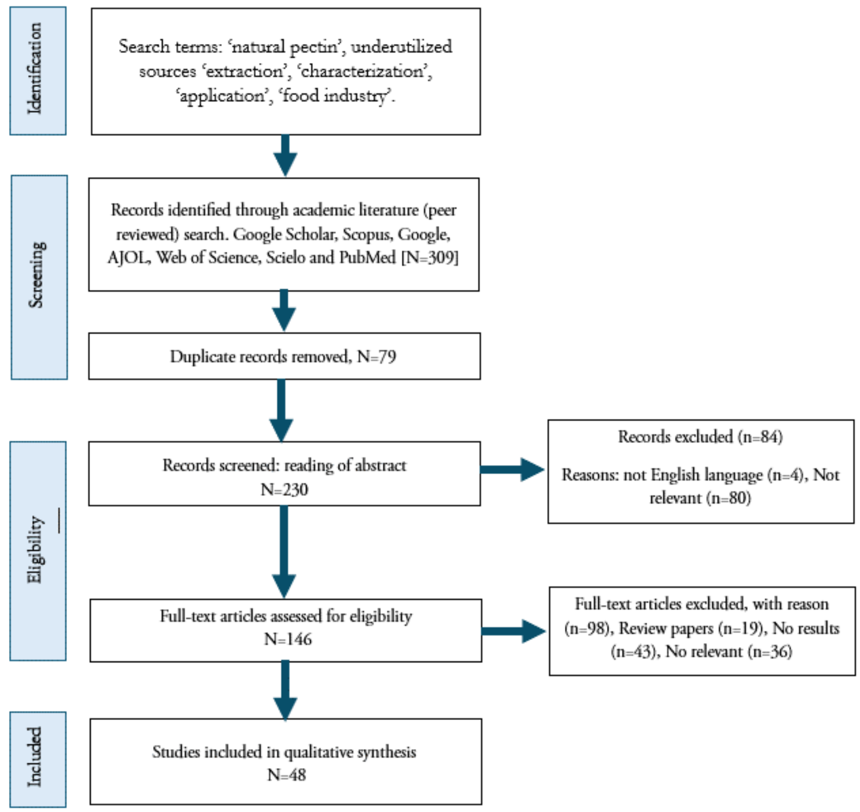

Figure 1. An Overview of the Inclusion and Exclusion Criteria of Research Articles

exploration of novel pectin-rich materials (Şen *et al.*, 2023). Growing awareness of the health benefits associated with dietary fibers, including pectin, may also have driven research into its functional properties (Lasunon *et al.*, 2022). The versatility of pectin in various food applications, including its use as a gelling agent, thickener, and stabilizer, has attracted attention from the food industry. The exploration of pectin in new food products, such as plant-based alternatives and functional foods, has contributed to the increase in published studies (Ralet *et al.*, 2001).

3.2 Distribution of articles over continents

The results presented in Figure 3 indicate that the majority of the studies on pectin extraction and its application in food industry were conducted in Asia (n=31) followed by Africa (n=6), South America (n=4), Europe (n=3), North America (n=3), and Oceania (n=1). Among the 31

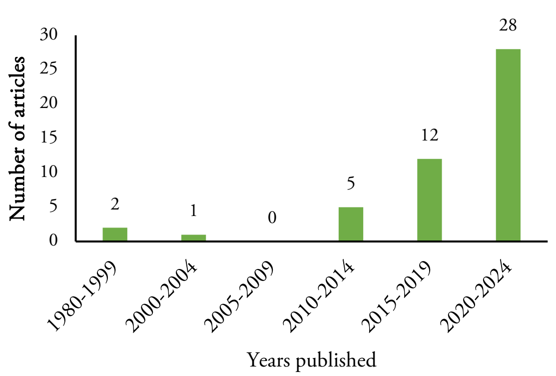

Figure 2. Distribution of Reviewed Articles Over Years

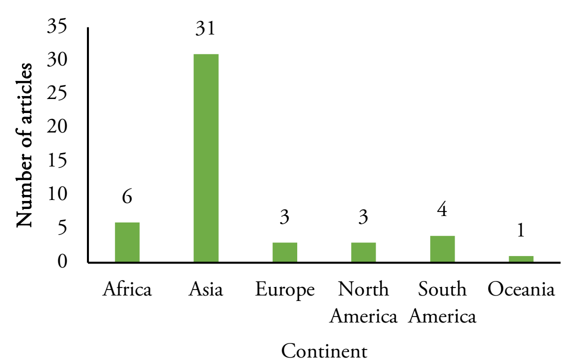

Figure 3. Distribution of Articles Over Continents

publications originating from Asia, China accounted for the highest number (n=8). African studies were conducted in South Africa, Morocco, Sudan, Egypt, Ethiopia and Nigeria, demonstrating a growing interest in the valorization of indigenous agricultural residues for pectin extraction across the continent.

Asian countries, particularly those with robust agricultural sectors such as China and India, tend to benefit from more substantial funding for research and development in food technology. Such financial support enables comprehensive investigations into pectin extraction methodologies and their applications, thereby contributing to a greater volume of scholarly output (Lekhuleni *et al.,* 2021). Moreover, Asia is home to a wide array of pectin-rich fruits and plants, including citrus fruits, apples, and tropical varieties (Zhu *et al.,* 2022). This biodiversity offers extensive opportunities for research and innovation in extraction processes, which may in turn lead to increased publication rates. Conversely, although Africa possesses its own pectin-rich resources, such as okra and prickly pear (Dambuza *et al.,* 2024; Mamiru *et al.,* 2023), the overall diversity and commercial exploitation of these resources appear comparatively limited, thereby constraining the scope of research (Khamsucharit *et al.,* 2018). Furthermore, Asian researchers often benefit from enhanced access to international collaborations and academic networks, which facilitate the exchange of knowledge and resources (Gurev *et al.,* 2023). This interconnectedness likely contributes to higher research productivity, whereas African researchers may encounter difficulties in establishing comparable networks, potentially hindering their research output (Sengkhamparn, 2009).

3.3 Common Sources of Pectin

As displayed in Figure 4, citrus (n = 19) constituted the primary source of pectin, whereas pome (n = 1) was the least utilized. The peel was the most frequently employed fruit part for pectin extraction, featuring in 22 articles, as presented in Table 1. Of the reviewed articles, pectin was predominantly extracted from by-products (n = 40), as opposed to whole fruit (n = 8). This preference for by-products is likely attributable to the imperative to valorise industrial residues, thereby contributing to the reduction of food waste and aligning with sustainability objectives within the food sector (Sangta *et al.,* 2024). Moreover, by-products are generally more cost-effective than whole fruits, thereby enhancing the economic feasibility of the extraction process (Mamiru *et al.,* 2023). In addition, by-products such as peels and seeds often exhibit higher pectin concentrations than the corresponding fruit flesh (Dong *et al.,* 2021).

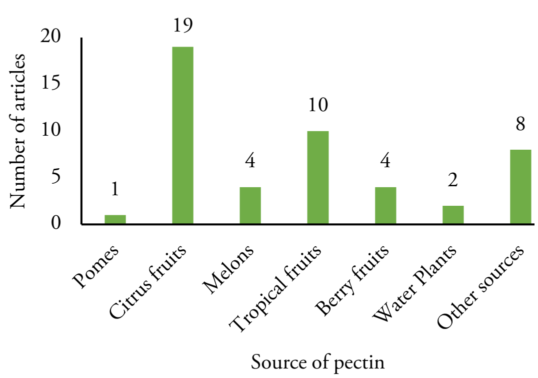

Figure 4. Common Sources of Pectin

Tropical fruits represented the second most prevalent source of pectin (n = 10). Among these, gold kiwi, dragon fruit, and jackfruit were identified as the species from which pectin was isolated (Table 1). The pectin content in kiwi fruit including both green and gold varieties, has been reported to be approximately 0.9% of fresh weight (Islam *et al.,* 2023). Dragon fruit, particularly the red-fleshed variety, has been found to contain pectin ranging from 0.46% to 0.75% of fresh weight (Wu *et al.*, 2006). Furthermore, studies indicate that the pectin in jackfruit varies between 1.0% and 2.5% of fresh weight (Ngo *et al.,* 2023). Citrus peels, especially those derived from oranges and lemons, are characterized by high pectin levels, rendering them an efficient and economically advantageous substrate for extraction (Yapo *et al.,* 2009). Additional sources explored in the literature include cocoa pods, sunflower heads, sugar beet pulp, onion waste, and water hyacinth.

The extraction methodologies for citrus pectin are well-established and have been extensively optimized, resulting in efficient processes that yield high-quality pectin (Fishman *et al.,* 2000). The combined economic advantages of utilizing a readily available and inexpensive raw material, coupled with well-established extraction processes, render citrus pectin a cost-effective option for industrial producers (Levigne *et al.,* 2002).

3.4 Common Extraction Methods of Pectin

Table 1 indicates that, various methods can be employed to extract pectin, the methods include acid extraction, microwave assisted extraction, intermitted microwave assisted, hot water, extraction, continuous subcritical water extraction, Soxhlet acid extraction, base acid extraction, non-acid ultrasonic assisted extraction, enzyme extraction, chemical and ultrasound-assisted extraction, ammonium oxalate/oxalic acid extraction and acetone extraction. Table 2 displays that acid extraction with (n = 23) was the most common method used for pectin extraction followed by microwave assisted method (n = 8), then intermittent microwave method (n = 3) and ultrasound assisted method (n

Table 2. Method of Pectin Extraction, Source and Continent

Type of Extraction Method	Method of Extraction	Pectin Source	Continent
Conventional	Acid Extraction	Citrus (11); Berry (3); tropical fruits (1); Water plants (2); other sources (4).	Asia (15), Africa (4), South America (1), North America (1) and Europe (1)
	Soxhlet Acid Extraction	Berry (1)	Africa
	Hot Water Extraction	Tropical (1)	Asia
	Ammonium Oxalate/Oxalic	Citrus (1)	Asia
	Base Acid Extraction	Citrus (1)	Asia
	Sodium Citrate Extraction	Other source (1) (sunflower head)	Asia
	Acetone Extraction	Citrus (1)	Asia
Green Technology	Surfactant and Microwave Assisted Extraction	Citrus (1)	Asia
	Microwave Assisted	Citrus (3); Berry (1); Tropical (2); Pome (2) and Flaxseed (1).	Asia (5); Africa (2) and Europe (2).
	Enzyme Extraction	Topical (1)	Oceania
	Continuous Subcritical Water Extraction System	Tropical (1)	Asia
	Intermittent Microwave	Citrus (1) and Tropical (1)	Asia (1) and North America (1).
	Ultrasound-Assisted Extraction	Tropical (1), Other sources (4) (cocoa pod, Onion waste, tomato waste)	Africa (1) South America (2) and Asia (2)
	Non-Acid Ultrasonic Assisted	Citrus (1)	Asia

= 4). Table 1 further reveals that acid extraction method was primarily employed in Asia (n = 18) in extracting pectin principally from citrus fruits. The utilization of acid extraction method mostly may be possibly due to its ability to efficiently breakdown the plant cell walls, thus giving a high pectin yield. Acid extraction does not require sophisticated equipment thus, cost effective and accessible to both research and industries (Kazemi *et al.,* 2019). This extraction method is also versatile and compatible with a wide range of pectin-rich sources (Yapo, 2009).

As illustrated in Figure 5, of the 48 articles reviewed, 28 employed conventional extraction techniques, chiefly acid extraction and hot water extraction, whereas 20 reported on green technology extraction methods, including microwave assisted, enzyme assisted-extraction, continuous subcritical water extraction system, ultrasound assisted, non-acid ultrasonic-assisted extraction and intermittent microwave-assisted extraction. The first publication on green technology extraction technologies appeared nearly three decades after the initial study on pectin extraction, which was reported in 1988, with the former emerging in 2018.

The predominance of conventional extraction methods may be ascribed to their well-established nature and extensive optimization, which render them widely adopted in industrial settings (Bagherian *et al.,* 2011). Conversely, the progressive transition towards green technologies might be attributed to the increasing emphasis on the development of more sustainable and environmentally benign extraction processes. This shift aligns with broader objectives to reduce the reliance on harsh chemical agents, favoring solvents such as water or mildly acidified water, whilst simultaneously minimizing energy consumption and mitigating overall environmental impact (Şen et al., 2023).

Although green extraction technologies, such as microwave-assisted and ultrasound-assisted methods, have attracted growing scholarly interest owing to their reduced extraction time, lower solvent consumption, enhanced extraction efficiency, and reduced environmental impact, their industrial uptake remains constrained by several practical barriers. These include high capital investment requirements, elevated energy demands, and the need for specialised equipment (Adetunji *et al.,* 2017; Bagherian *et al.,* 2011). By contrast, conventional acid extraction continues to predominate in industrial pectin production, largely due to its operational simplicity, lower implementation costs, well

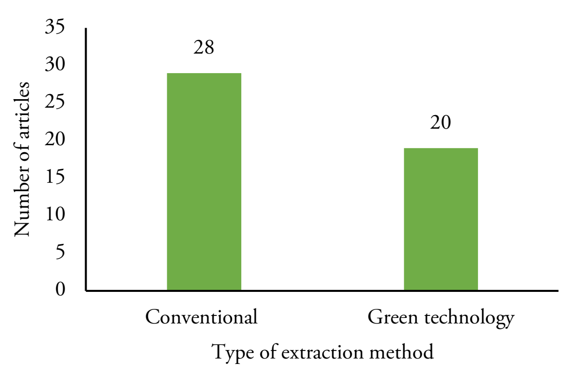

Figure 5. Distribution of Types of Pectin Extraction Methods

established scalability, and extensive familiarity within the industry (Thakur *et al.,* 1997; Yapo, 2009). Therefore, while green technologies present promising sustainable alternatives, comprehensive techno-economic and life-cycle assessments are still required to determine their commercial feasibility and scalability within industrial food systems.

3.5 Applications of Natural Pectin in Food Systems

The review identified 11 specific studies that focused on the application of extracted natural pectin in food systems, representing a small subset of the total 48 articles published on pectin extraction and applications. The findings are summarized in Table 3.

The focus of only eleven out of 48 articles on pectin applications in food systems suggests a disproportionate emphasis on pectin extraction methods and characterization rather than direct applications. This may be attributed to several factors which include limited industry collaboration as several studies may lack the partnerships with food manufacturers necessary to translate extraction findings into practical applications as well as lack of specialized expertise: as applying pectin in diverse food systems requires multidisciplinary expertise in food chemistry, engineering, and microbiology, which may be beyond the scope of some research teams (Thakur *et al.,* 1997).

Although this review explored sources, extraction methods, characterization, and food-system applications of natural pectin, the findings revealed that most published studies primarily focus on extraction optimization and physicochemical characterization, with comparatively fewer studies evaluating practical food applications. Only a limited number of studies investigated applications such as edible coatings, beverage stabilization, active packaging, functional foods, and jam production. This highlights a considerable research gap and demonstrates the necessity for more translational studies evaluating the industrial and functional applications of natural pectin in food systems.

4 Conclusion

The results of this review revealed that research on pectin use is on the increase, with 28 articles published during the period 2020 to 2024, and most of the published articles were studies conducted in Asia. Citrus fruit peels remain the primary natural source, with acid extraction being the most frequently used method. In addition, the review disclosed that the principal source of natural pectin is citrus fruits, primarily peels as a by-product, with conventional methods, such as acid extraction, being the common extraction techniques. As consumer demand for natural and clean-label products increases, there is a need for a deeper understanding of pectin extraction techniques and alternative sources. Future research should explore sustainable extraction methods, such as enzymatic, microwave-assisted, and Natural Deep Eutectic Solvent (NADES) techniques, to improve efficiency while minimizing chemical residues. Investigating underutilized sources, including tropical fruits, vegetables, and agricultural by-products, could expand pectin production and industrial use. By optimizing extraction and broadening its applications, pectin can contribute to sustainable, health-focused innovations across various industries.

Table 3. Various Applications of Extracted Pectin in Food Technology

Pectin Source	Utilization	Impact	Reference
Coffee pulp	Active packaging	Improved shelf life	Biratu *et al.* (2024)
Tomato Waste	Functional foods		Lasunon *et al.* (2022)
Banana Peel	Edible Coating for Mozzarella Cheese	Reduced moisture loss and microbial growth on the cheese surface.	Rivadeneira *et al.* (2020)
Flaxseed Cake	Edible Coating for Pear Fruits	Preserved freshness and reduced post-harvest losses	Ahmad *et al.* (2021)
Kiwi Peel	Dietary fiber		Karbuz & Tuğrul (2021)
Sentul Peel	Edible Coating for Tomatoes	Improved shelf life by minimizing microbial spoilage and maintaining firmness.	Riza *et al.* (2021)
Lemon Peel	Watermelon jam	Excellent gelling properties.	Dhushane & Mahendran (2020)
Sweet Potato	Gelling agent and food stabilizer	Produced low-ester pectin with excellent calcium-induced gelation	Han *et al.* (2024)
Pomelo	Jelly and Milk Fruit Drink	Prevent phase separation in the drink and excellent gelling ability for jelly formation.	Swamy & Muthukumarappan (2017)
Watermelon Peel	Edible food films	Preserved freshness and improved shelf life	Prakash Maran *et al.* (2014)
Lemon and Orange Peel	Jam production	Strong gelling properties and enhanced the texture and spreadability of the jam.	Kaya *et al.* (2014)

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